Campus Networking Workshop
CIS 399

BGP Theory and Configuration

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Network Startup Resource Center

Program

- Using BGP Attributes
- Implementing IBGP
- Implementing EBGP
- Emphasis in Stability, Scalability and Configuration Examples

BGP Review

Why use BGP?

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What we want to achieve

- Implement routing policies that are:
  - *Scalable*
  - *Stable*
  - *Simple*

More Details ...

- You need to scale your IGP
- You are a client with two external connections
- You need to receive all Internet routes
- You need to implement a consisten routing policy or expand your QoS policy

BGP Updates

Withdrawals
Attributes
Prefixes (NLRI - Network-Layer Reachability Information)

BGP Attributes for Routing Policy Definition

- ORIGIN
- AS-PATH
- NEXT-HOP
- MED
- LOCAL_PREF
- ATOMIC_AGGREGATE
- AGGREGATOR
- COMMUNITY
- ORIGINATOR_ID
- CLUSTER_LIST
- MP_REACH_NLRI
- MP_UNREACH_NLRI

External BGP (eBGP)

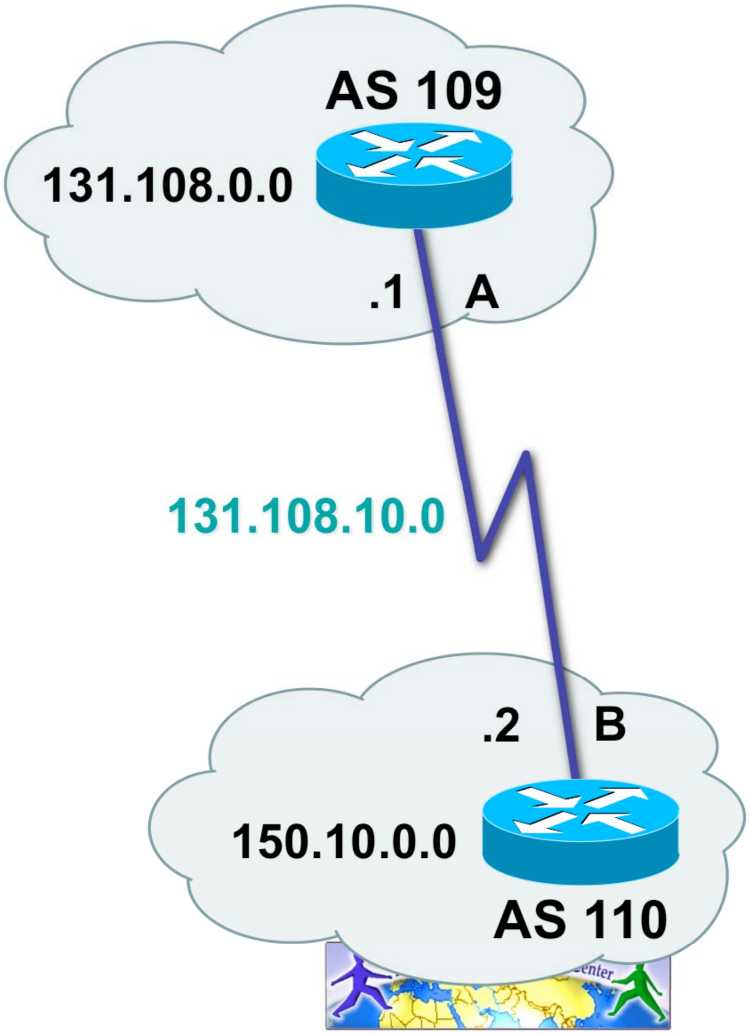
- **Between routers in different ASNs**
- **Usually with a direct conexion**
- **With next-hop pointing to itself**

- Router B

  router bgp 110
  neighbor 131.108.10.1 remote-as 109

- Router A

  router bgp 109
  neighbor 131.108.10.2 remote-as 110



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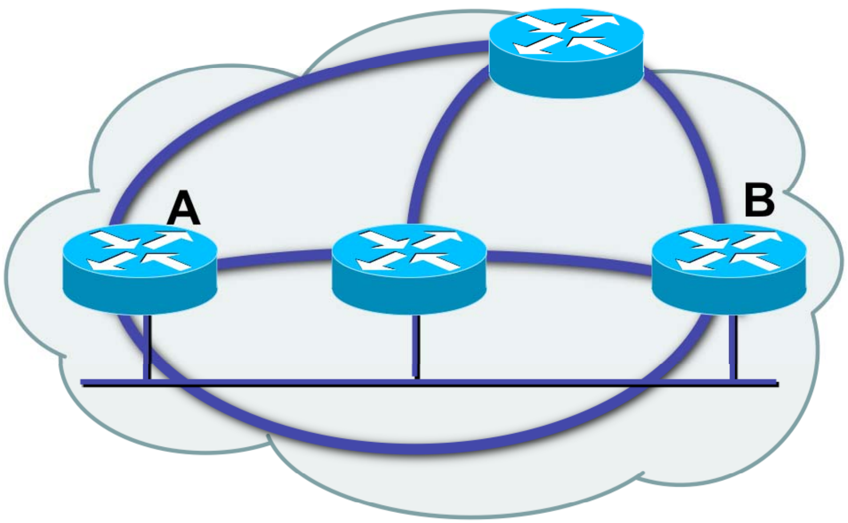
Internal BGP

- Neighbors within the same ASN
- Don’t modify next-hop
- Not necessarily with a direct connection
- Don’t announce routes learn by other iBGP peers



Router B:

router bgp 109

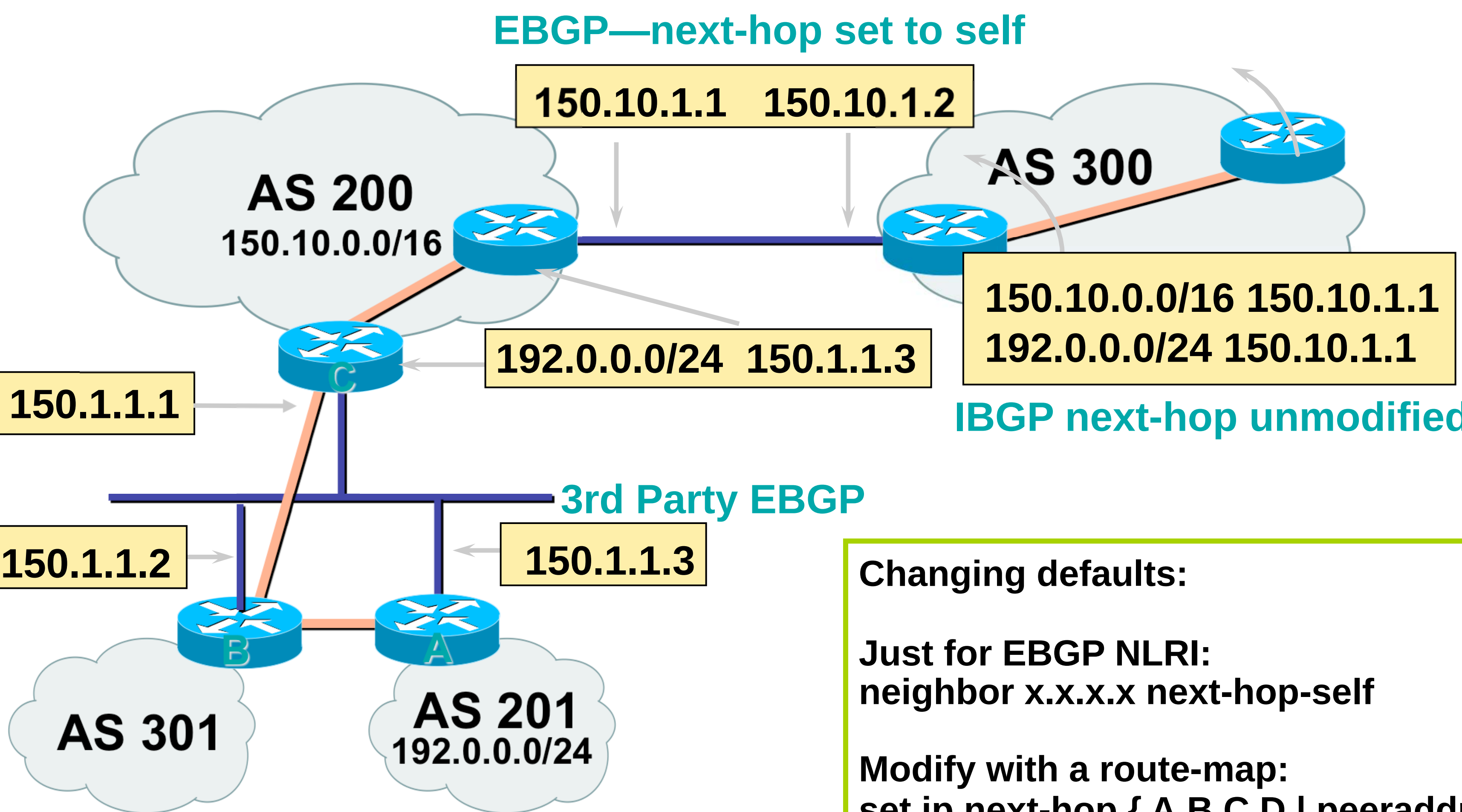
neighbor 131.108.30.2 remote-as 109

Router A:

router bgp 109

neighbor 131.108.20.1 remote-as 109

BGP Attributes: NEXT_HOP

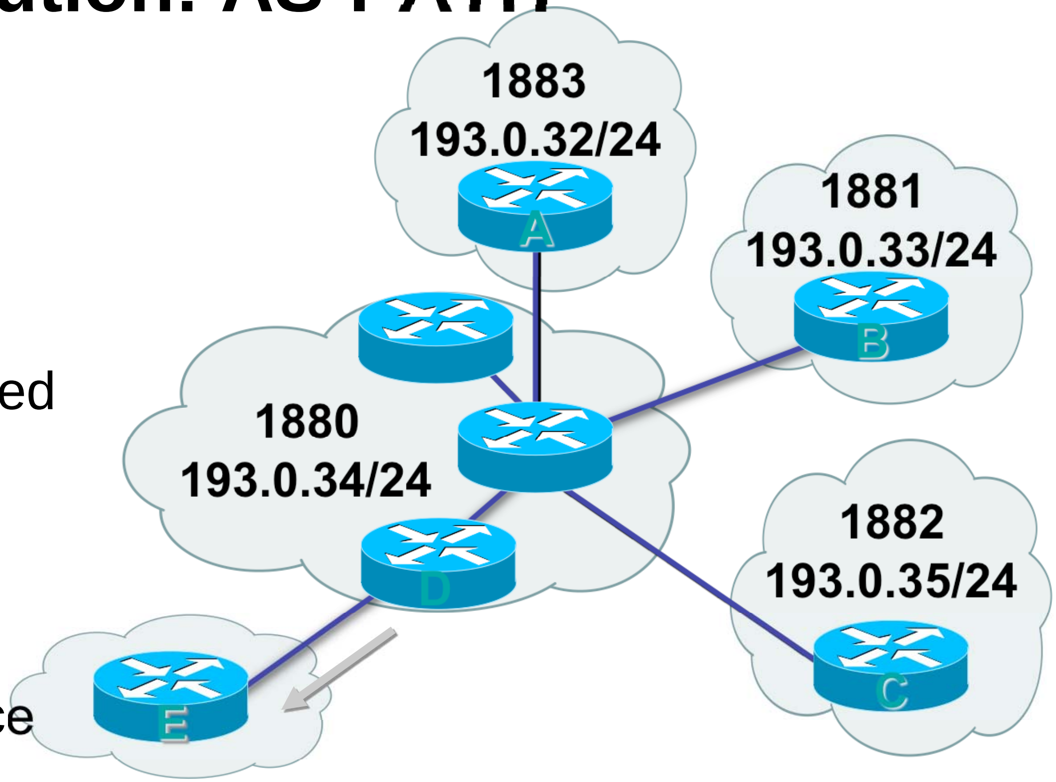


Changing defaults:

Just for EBGP NLRI:
neighbor x.x.x.x next-hop-self

Modify with a route-map:
set ip next-hop { A.B.C.D | peeraddress}

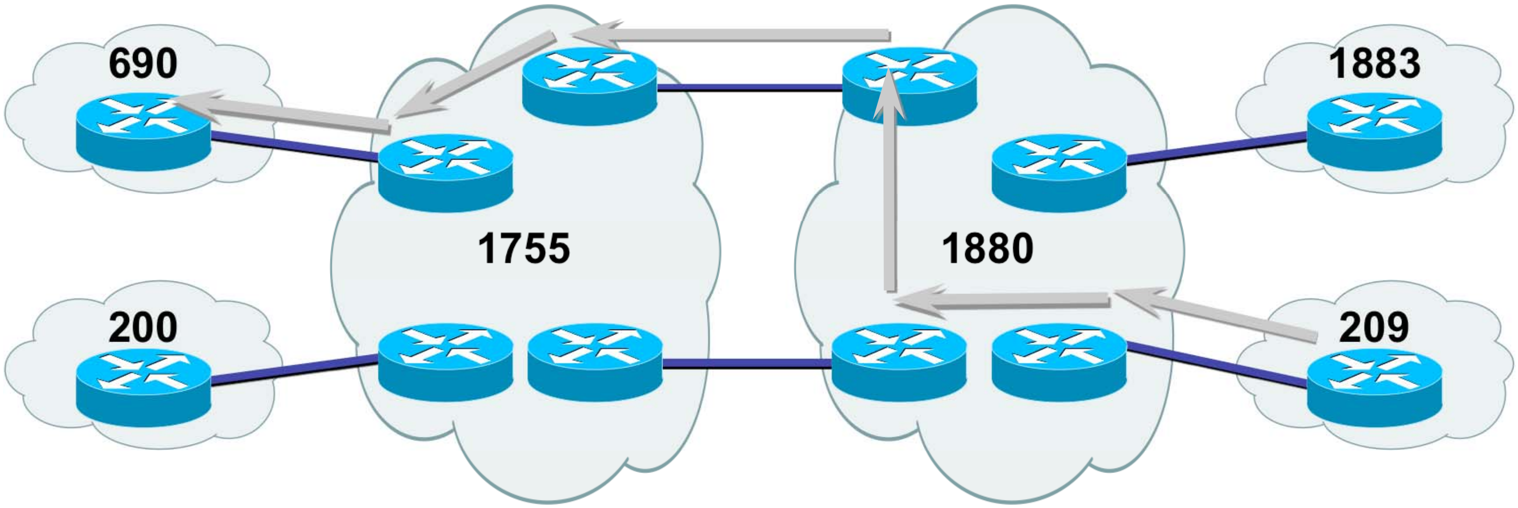
Problem: Loop detection, Policies
Solution: AS-PATH



- AS Sequence
  - –List of ASN the advertisement has traversed
- AS Set
  - –Summarizes an AS Sequence
  - –The order in the sequence is lost
- Modify with route-map: *set as-path*

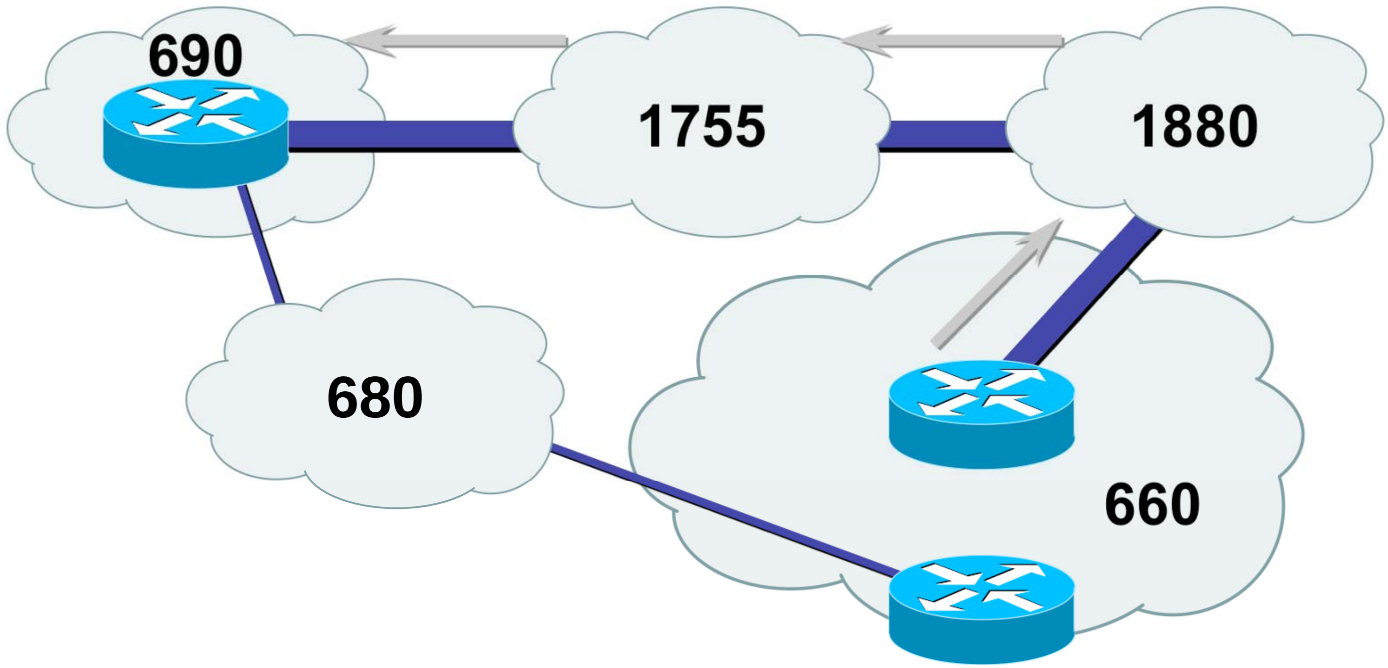
A: 193.0.33/24 1880 1881
B: 193.0.34/24 1880
C: 193.0.32/24 1880 1883
E: 193.0.32/22 1880 {1881, 1882,1883}

Problem: Indicate the best path to an AS
Solution: MED



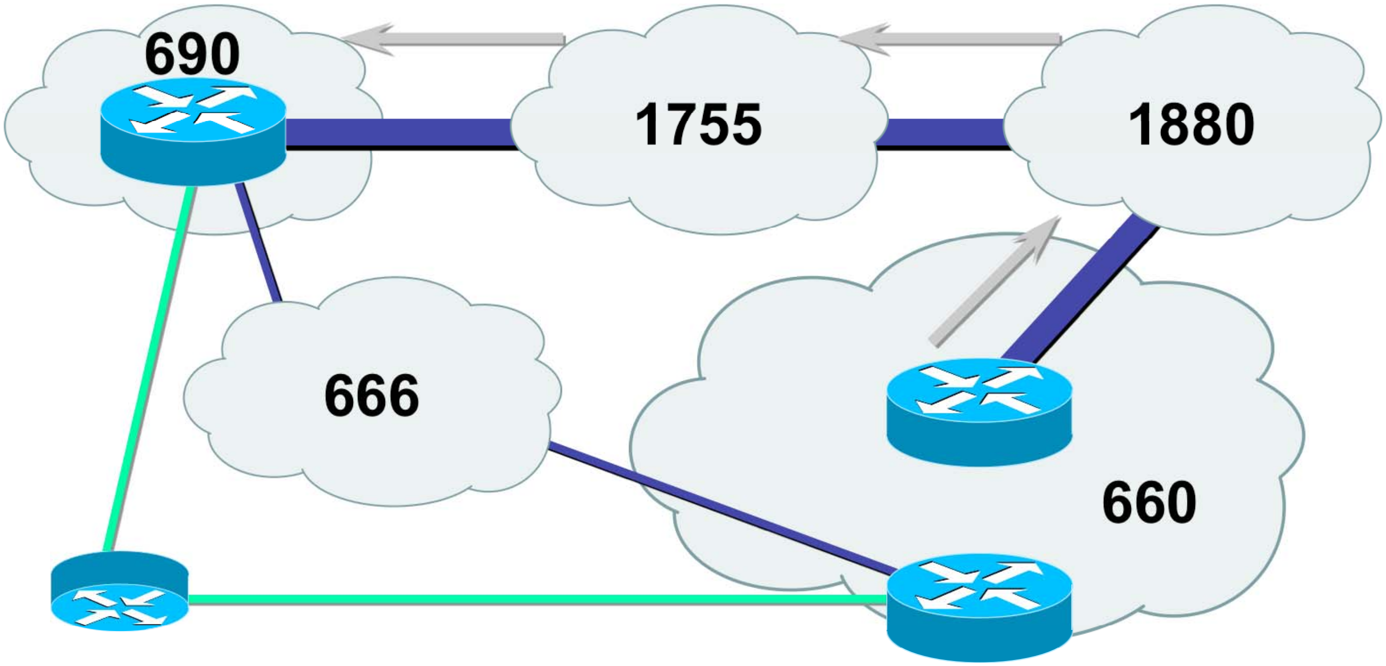
- Informs about an entry point preference
- Is compared if the path is to the same AS
  – Unless you use "bgp always-compare-med"
- Is a non-transitive attribute
- In a route-map: *set metric*
  set metric-type internal

Problem: Overriding MED/AS-PATH
Solution: Local Preference



- Attribute is local to the AS – mandatory for iBGP updates
- route-map: *set local-preference*

Problem: Overriding Local Preference
Solution: Weight



- Local to the router where is configured
- route-map: *set weight*
- The highest weight wins over all the valid paths

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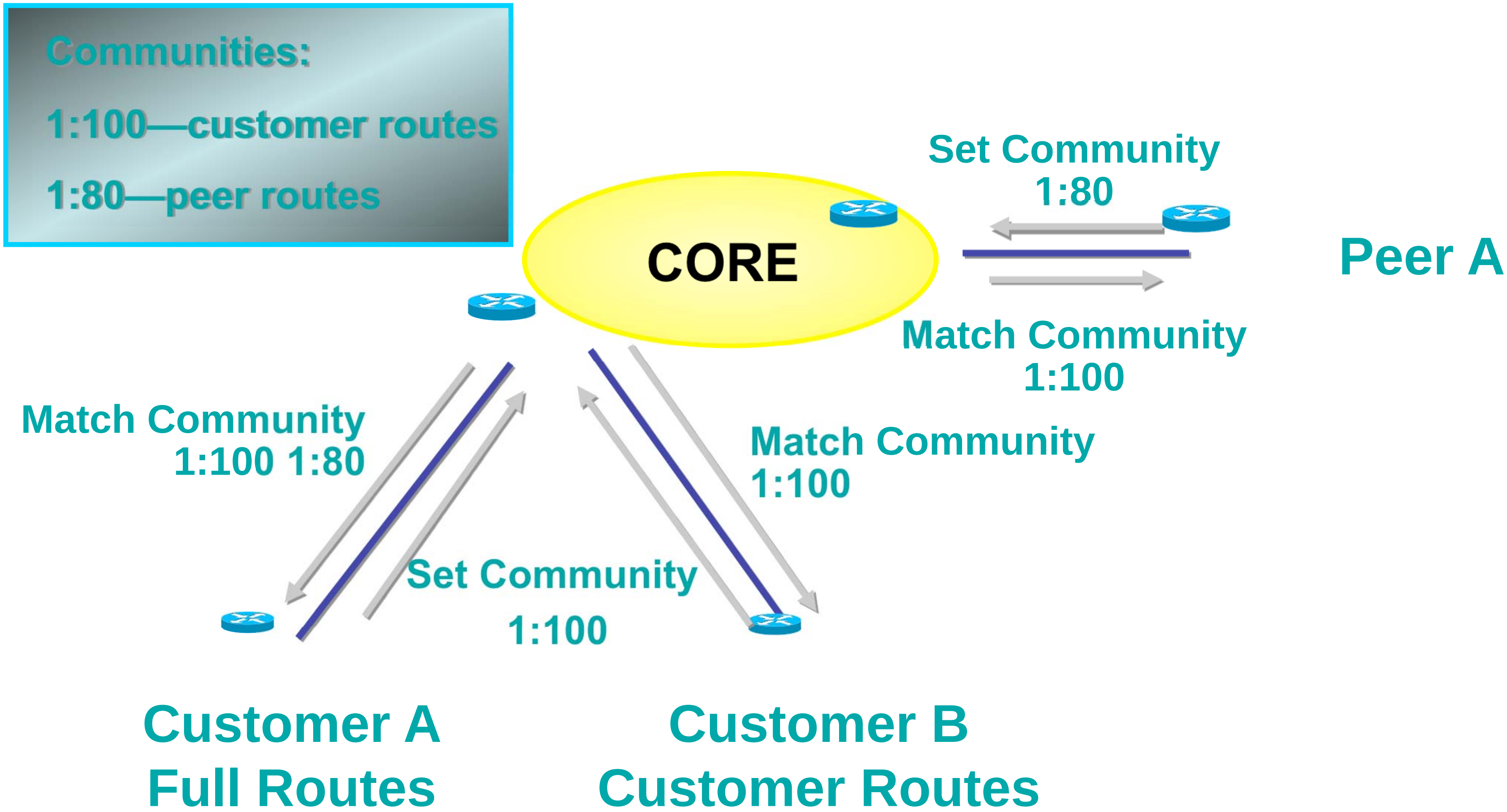
Problem: Scaling Routing Policies
Solution: COMMUNITY



BGP Attributes: COMMUNITY

- Groups destinations to help scale policy application
- Typical Communities:
  - Prefixes learned from customers
  - Prefixes learned from peers
  - Prefixes in a VPN
  - Prefixes with preferential treatment in queuing

BGP Attributes: COMMUNITY

- Activated per neighbor/peer-group:
  - *neighbor {peer-address | peer-group-name} send-community*
- Transitive across AS boundaries
- Common format is a 4-bytes string <AS>:[0-65536]

BGP Attributes: COMMUNITY

- Each prefix can be a member of several communities
- Route-map: *set community*
  - <1-4294967295> community number
  - aa:nn community number in aa:nn format
  - *additive Adds to a list of existing communities*
  - *local-AS Do not send to EBGP neighbors (well-known community)*
  - *no-advertise Do not send to any peers (well-known community)*
  - *no-expert Do not expert outside of the AS/Confederation (well-known*
  - *community)*
  - *none No community attribute*

Least Used Attribute: ORIGIN

- IGP – created with a *network* command in the BGP configuration
- EGP – redistributed from an EGP
- Incomplete – redistributed from an IGP in the BGP configuration
- **NOTE** – always use a route-map to modify the origin: *set origin igp*

Set command in a route-map

• as-path	Prepends a string of AS to the AS-PATH attribute
• comm-list	Sets BGP community list (for deletion)
• community	BGP community attribute
• dampening	Sets BGP dampening formeters
• local-preference	BGP local preference attribute
• metric	Metric value for the destination routing protocol
• origin	BGP origin code
• weight	BGP weight for routing table
• ip next-hop	{ A.B.C.D | peer-address }

BGP Attributes

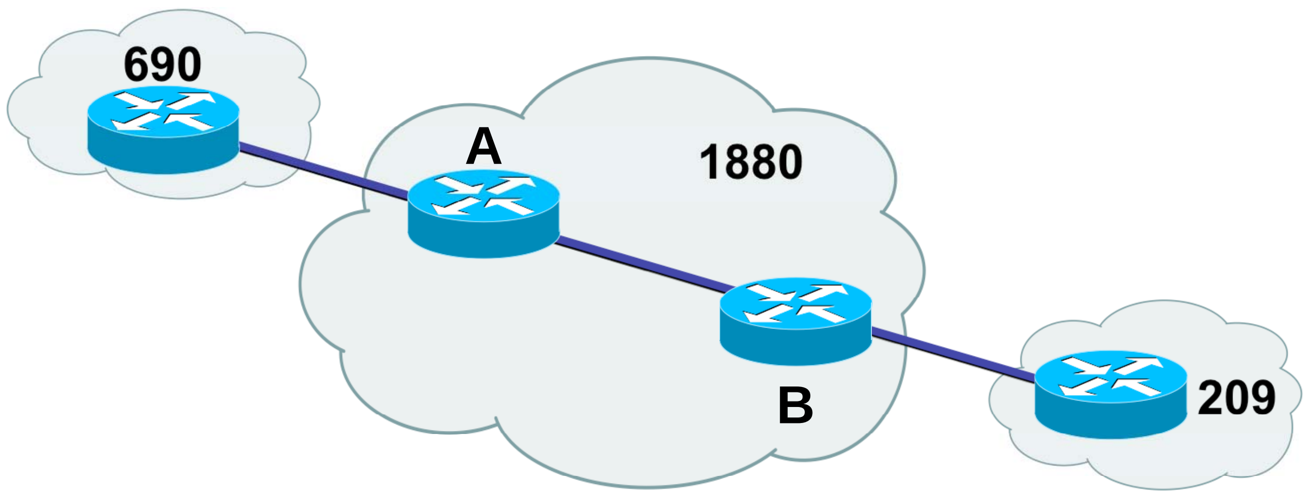
router1#sh ip bgp 10.0.0.0
BGP routing table entry for 10.0.0.0/24, version 139267814
Paths: (1 available, best #1)
  Not advertised to any peer
  ! AS-PATH   AS   ID
  65000 64000 {100 200}, (aggregated by 64000 16.0.0.2)
  ! NEXT-HOP   IGP METRIC   PEER-IP   PEER-ID
    10.0.10.4   (metric 10)   from 10.0.0.1 (10.0.0.2)
      Origin IGP, metric 100, localpref 230, valid, aggregated
      internal (or external or local),
      atomic-aggregate, best
      Community: 64000:3 100:0 200:10
      Originator: 10.0.0.1, Cluster list: 16.0.0.4, 16.0.0.14

Decision Algorithm

Only consider synchronized routes without AS loops and a valid next-hop, and then prefer:

- Highest WEIGHT
- Highest LOCAL PREFERENCE
- LOCALLY ORIGINATED (eg network/aggregate)
- Shortest AS-PATH
- Lowest ORIGIN (IGP < EGP < incomplete)
- Lowest MED
- EBGP
- IBGP
- Lowest IGP METRIC to next-hop
- Oldest external path
- Router with lowest Router ID
- Shortest CLUSTER_LIST length
- Lowest Neighbor IP address

Synchronization



- Router A won't announce prefixes to AS209 until its IGP has converged
- Make sure that iBGP next-hops are reachable via the IGP, and then:

```
router bgp 1880
  no synchronization
```

General Considerations

- Synchronization is not required if you have a full iBGP mesh
- Don’t let BGP override your IGP
- auto-summary: avoid. Instead use aggregation commands:

```
router bgp 100
  no synchronization
  no auto-summary
  distance 200 200 200
```

Until now …

- We can apply policies on a per AS basis
- Can group prefixes using communities
- Can chose entry and exit points for large policy groups using MED and local preference attributes

But, can the policies scale?

Implementing iBGP

Route Reflectors, Peer Groups

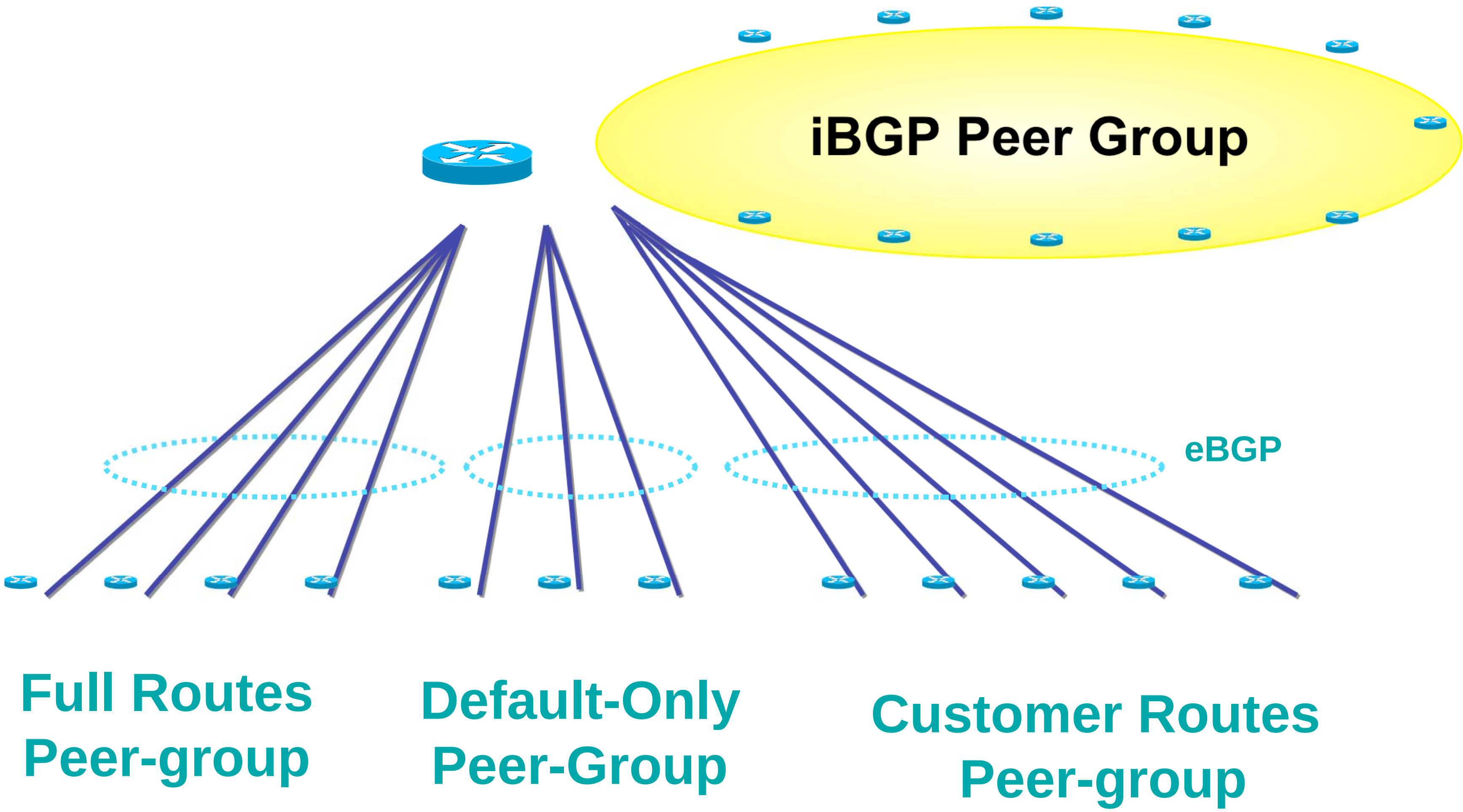
Guidelines for a Stable iBGP

- Peer using the loopback address
  - neighbor { ip address | peer-group} update-source loopback0
- Independent from physical interface failures
- Takes advantage of any IGP load-sharing

Guidelines for a Stable iBGP

- Use *peer-group* and *route-reflector*
- Only carry the next-hops in the IGP
- Carry full routes in BGP if it is necessary
- DO NO redistribute BGP into IGP

Using *Peer-Groups*

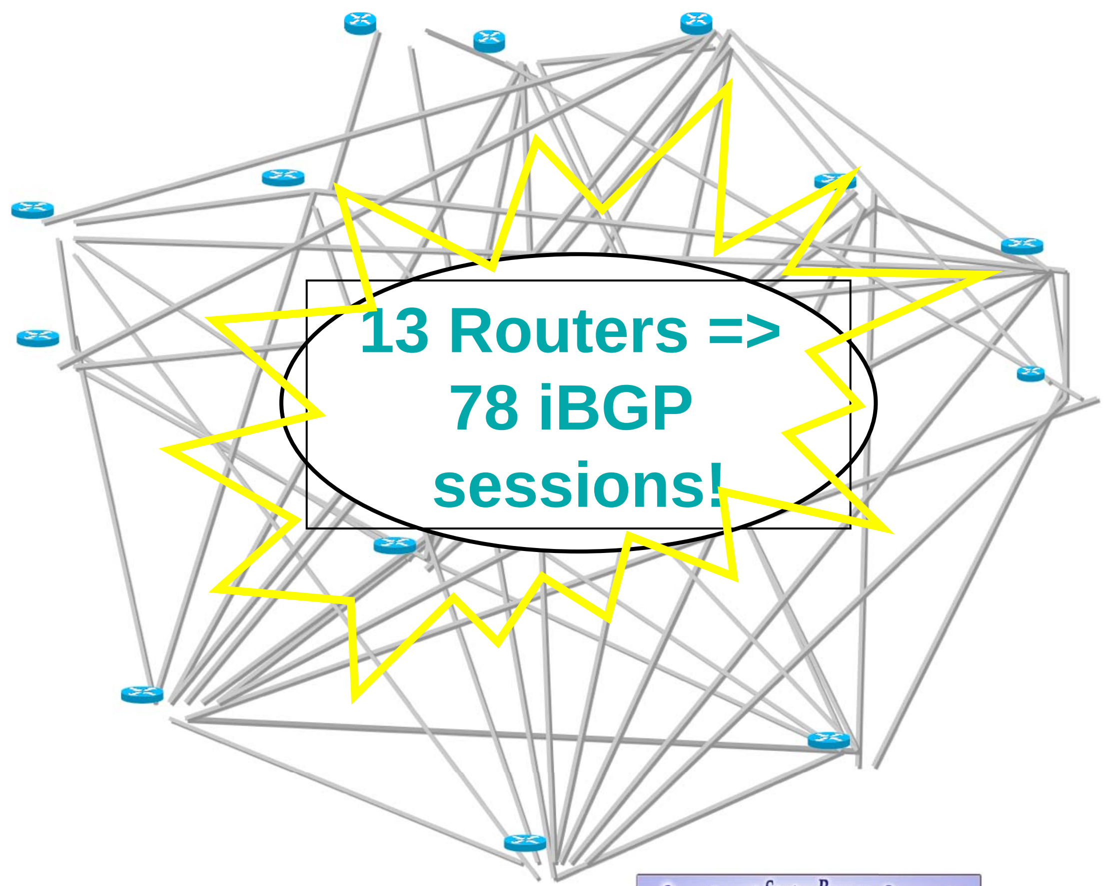


What is a *peer-group*?

- All members of a peer-group have a common outbound policy
- Updates are generated only once per peer-group
- Simplifies configuration
- Members can have different inbound policies

Why use a Route-reflector?

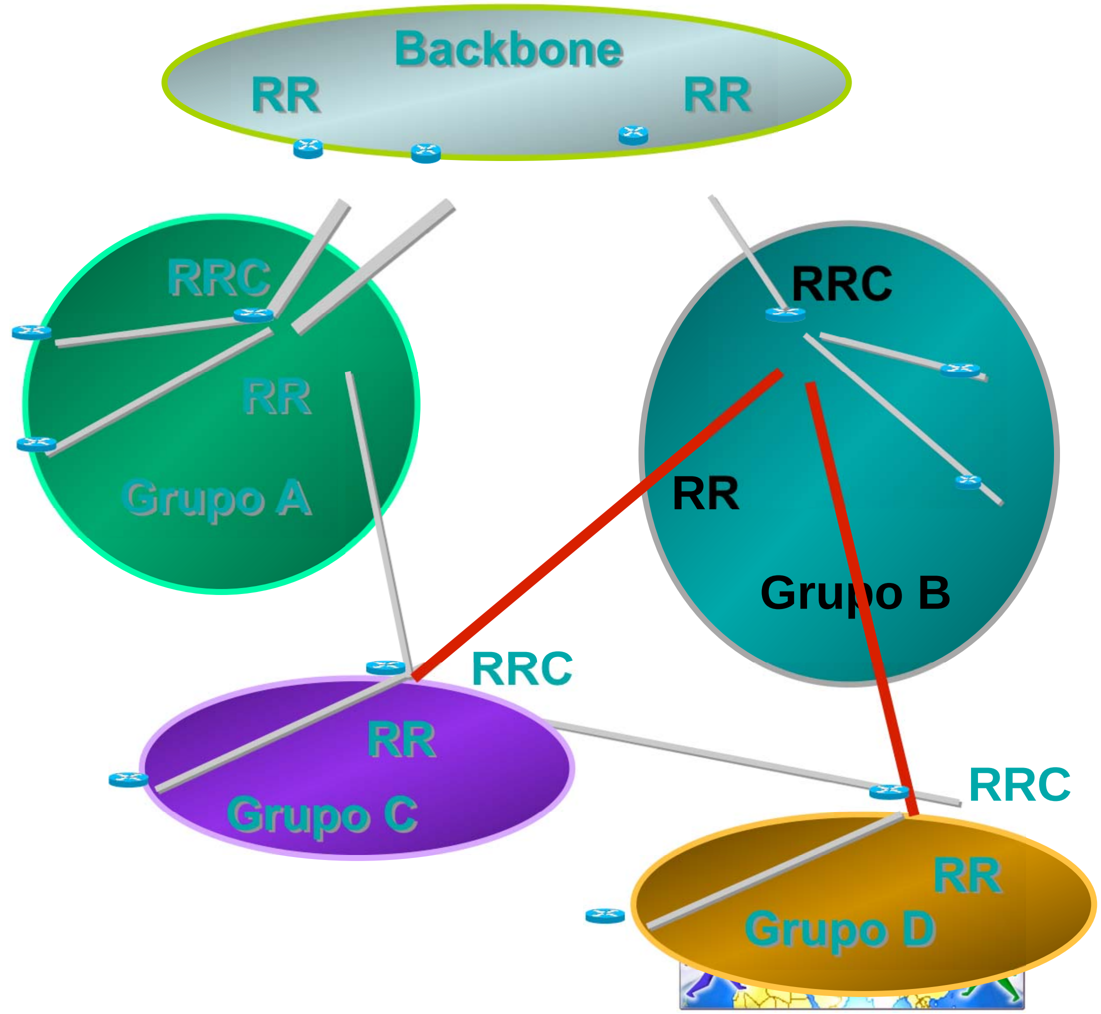
To avoid having a full mesh with N(n-1)/2 sessions



n=1000 => almost half a million iBGP sessions!

Using *Route-Reflectors*

Rule for RR Loop Avoidance: RR topology should follow the physical topology



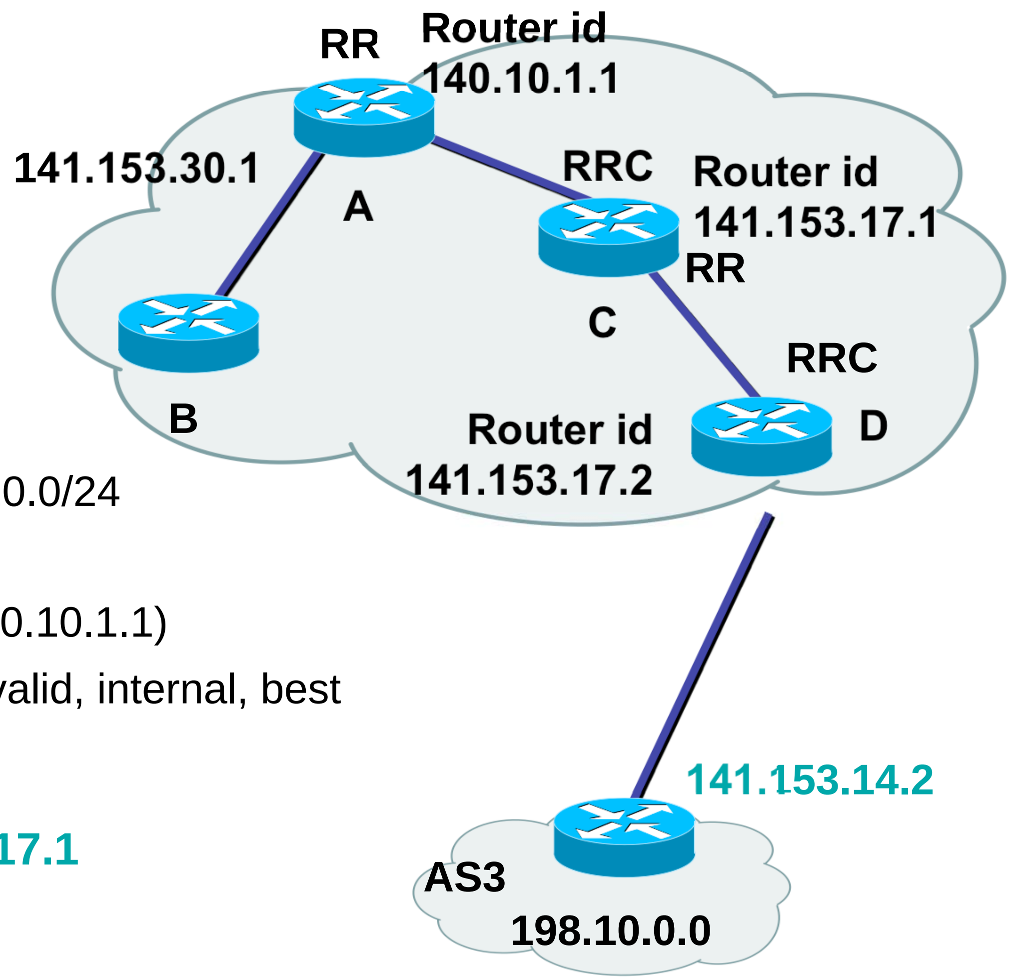
What is a *Route-Reflector*?

- The reflector receives path updates from clients and non-clients
- If the path is from a client, reflect it to clients and non-clients
- If the best path is from a non-client, reflect it only to the clients

Deploying *Route-Reflectors*

- Split the backbone into different groups
- Each group contains at least one RR (multiple for redundancy), and multiple clients
- Build a iBGP full mesh for the RRs
- Utilize single IGP - next-hop is not modified by the RR

Hierarchical *Route-Reflector*



- Example:

  RouterB>sh ip bgp 198.10.0.0

  BGP routing table entry for 198.10.10.0/24

  3

  141.153.14.2 from 141.153.30.1 (140.10.1.1)

  Origin IGP, metric 0, localpref 100, valid, internal, best

  Originator: 141.153.17.2

  Cluster list: 144.10.1.1, 141.153.17.1

BGP Attributes: ORIGINATOR_ID

- ORIGINATOR_ID
  - Router ID of iBGP speaker that reflects the RR client routes to non-clients
  - Overriden by: *bgp cluster-id x.x.x.x*
- Useful for troubleshooting and loop detection

BGP Attributes: CLUSTER_LIST

- CLUSTER_LIST
  - String of ORIGINAROR_IDs through which the prefix has traversed
- Useful for troubleshooting and loop detection

Until now …

- Is the iBGP peering Stable?
  – Use of loopbacks for the connection
- Will it Scale?
  – Use *peer-groups*
  – Use *route-reflectors*
- Simple, hierarchical configuration?

Deploying eBGP

Customer & ISP Issues

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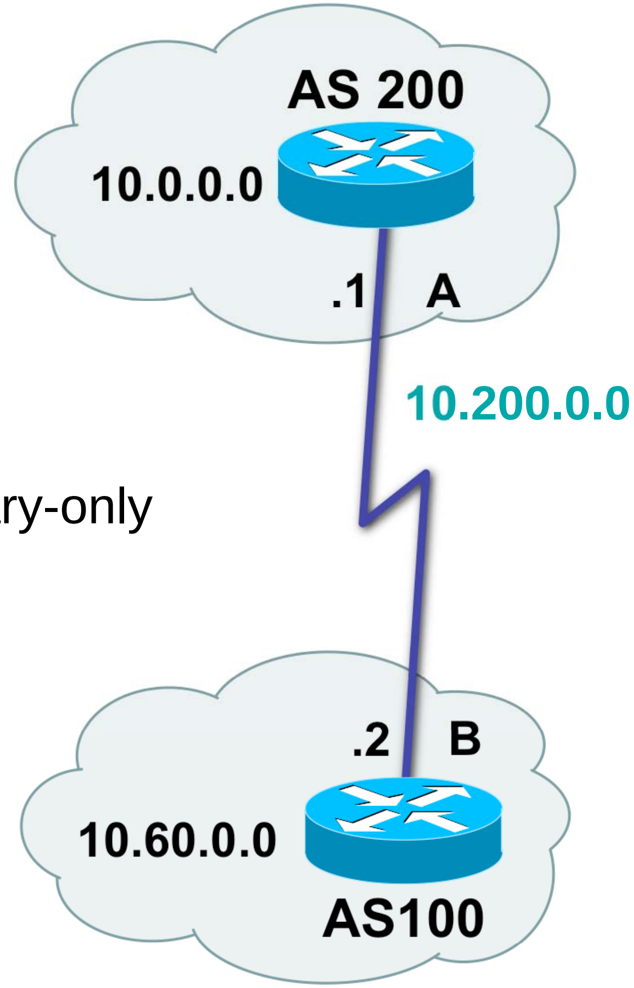
Customer Issues

- Procedure
  - Configure BGP (use session passwords!)
  - Generate a stable aggregate route
  - Configure Inbound Policy
  - Configure Outbound Policy
  - Configure loadsharing/multihoming

Connecting to an ISP

- **AS 100 is a customer of AS 200**
- **Usually with a direct conection**




```
Router B:
router bgp 100
  aggregate-address 10.60.0.0 255.255.0.0 summary-only
  neighbor 10.200.0.1 remote-as 200
  neighbor 10.200.0.1 route-map isp-out out
  neighbor 10.200.0.1 route-map isp-in in
```

What is Aggregation?

- Summarization based on specific routes *from the BGP routing tables*
  - 10.1.1.0 255.255.255.0
  - 10.2.0.0 255.255.0.0
  - => 10.0.0.0 255.0.0.0

How to Aggregate?

- aggregate-address 10.0.0.0 255.0.0.0 {as-set} {summary-only} {route-map}
- Use as-set to include path and community information from specific routes
- *summary-only* suppresses specific routes
- Use route-map to configure other attributes

Why Aggregate?

- Reduce the number of prefixes to announce
- Increase stability — aggregate routes are maintained even when specifics disappear
- How to generate stable aggregates:
  - router bgp 100
  - aggregate-address 10.0.0.0 255.0.0.0 as-set summary-only
  - network 10.1.0.0 255.255.0.0
  - :
  - ip route 10.1.0.0 255.255.0.0 null0

BGP Attributes: ATOMIC_AGGREGATE

- Indicates the loss of AS-PATH information
- Must not be removed once configured
- Configuration: *aggregate-address x.x.x.x*
- Is not set if the as-set keyword is used, however, AS-SET and COMMUNITY then carry information about the specifics

BGP Attributes: AGGREGATOR

- AS number and IP of router generating the aggregate
- Useful for troubleshooting

Attributes of the Aggregate

– NEXT_HOP = local (0.0.0.0)
– WEIGHT = 32768
– LOCAL_PREF = none (assumes 100)
– AS_PATH = AS_SET or nothing
– ORIGIN = IGP
– MED = none

Why an Inbound Policy?

- So we can apply a recognizable COMMUNITY that can be used in outbound filters and other policies
- Configure local-preference to override the default of 100
- Multihoming loadsharing
- Example:

```
route-map isp-in permit 10
 set local-preference 200
 set community 100:2
```

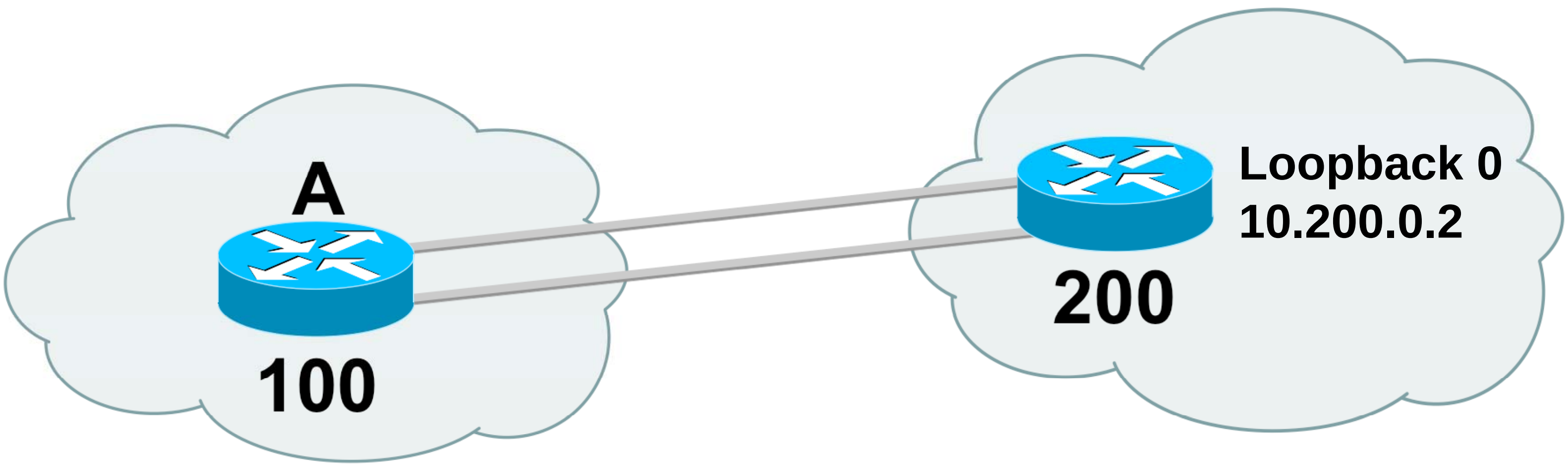
Why an Outbound Policy?

- Outbound prefix filters help protect against errors (can also apply as-path and community filters)
- Send communities based on agreements with ISP
- Example

```
route-map isp-out permit 10
 match ip address prefix-list outgoing
 set community 100:1 additive
```

Load-Sharing – One Path

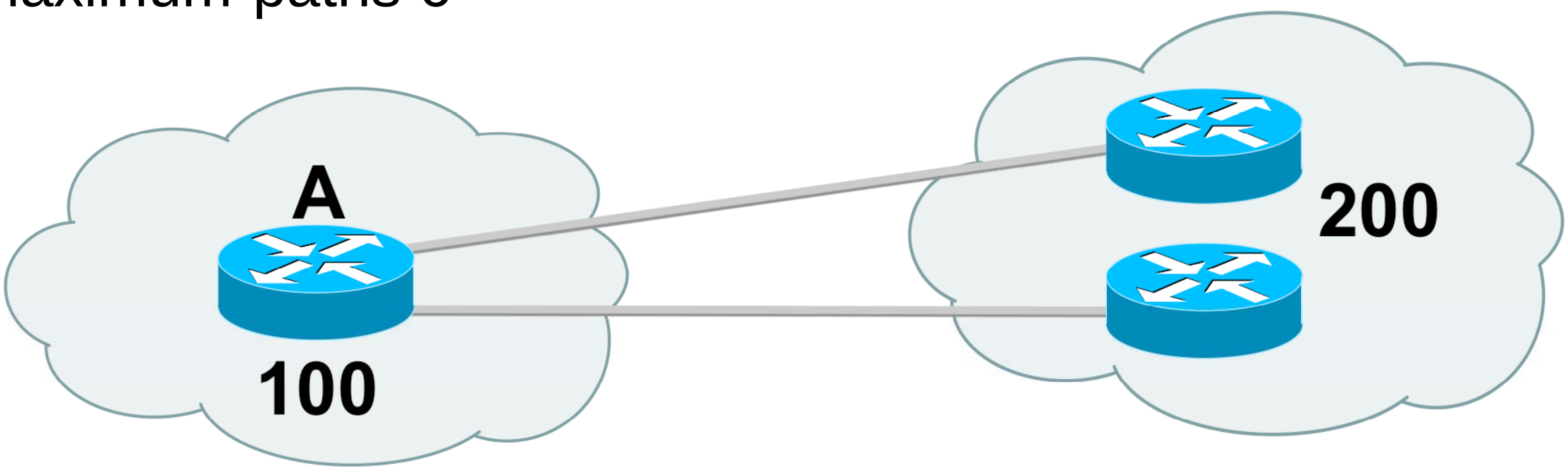
```
Router A:
interface loopback 0
  ip address 10.60.0.1 255.255.255.255
!
router bgp 100
  neighbor 10.200.0.2 remote-as 200
  neighbor 10.200.0.2 update-source loopback0
  neighbor 10.200.0.2 ebgp-multi-hop 2
```



Load-sharing – Multiple Paths/ Same AS

Router A:

```
router bgp 100
neighbor 10.200.0.1 remote-as 200
neighbor 10.300.0.1 remote-as 200
maximum-paths 6
```



What is Multihoming?

- Connecting to two or more ISPs to increase:
  - Reliability – if one ISP fails, still have others
  - Performance – better paths to common Internet destinations

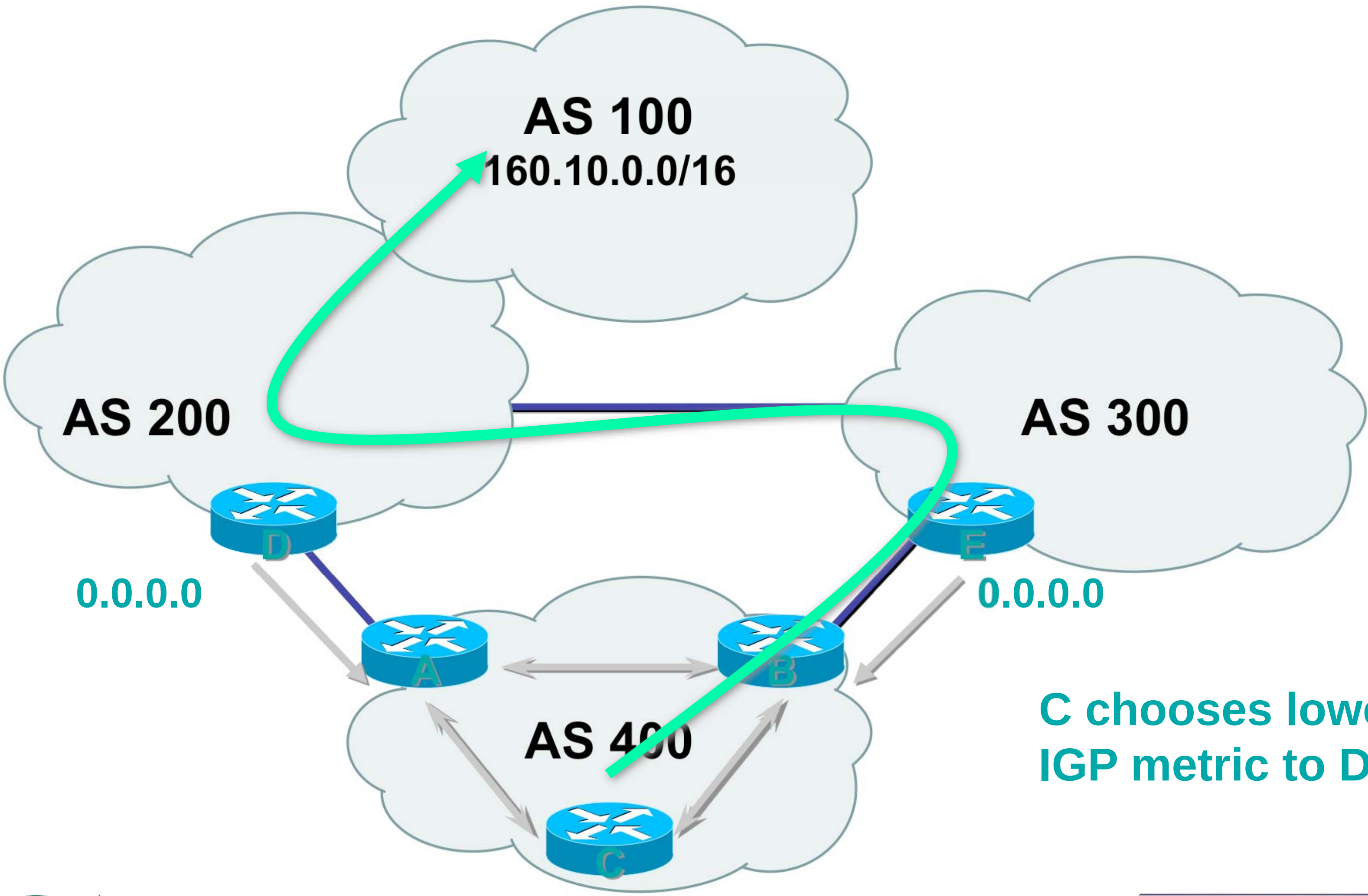
Types of Multihoming

- Three common cases:
  - Default route from all providers
  - Customer plus Default from all providers
  - Full routes from all providers

Default Route from All Providers

- Low memory and CPU requirements
- Provider sends BGP default => provider decides based on IGP metrics to reach default
- You send all your routes to the provider => inbound path decided by Internet
  - You can influence using AS-PATH prepend

Default Route from All Providers

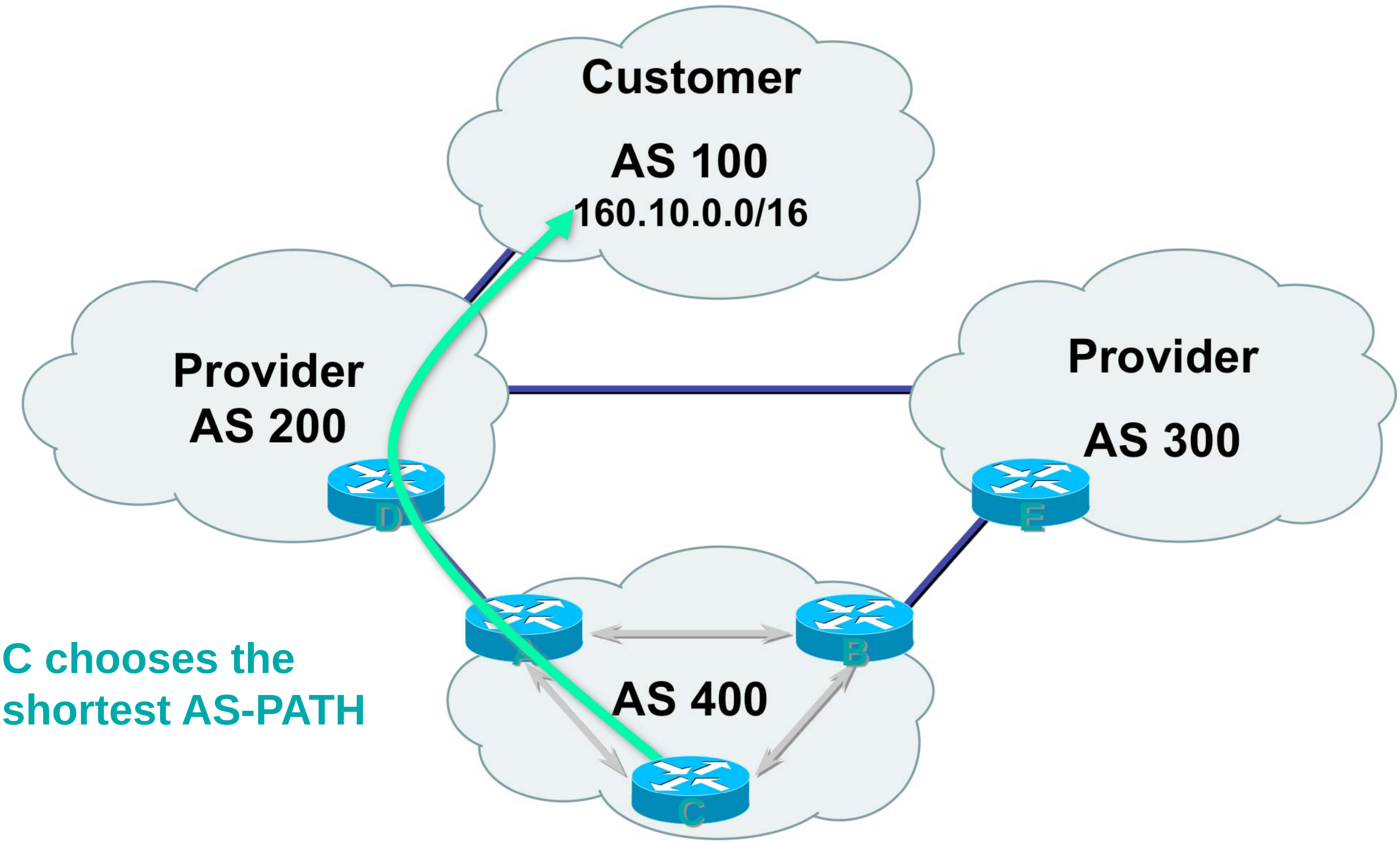


C chooses lowest IGP metric to Default

Customer+Default from All Providers

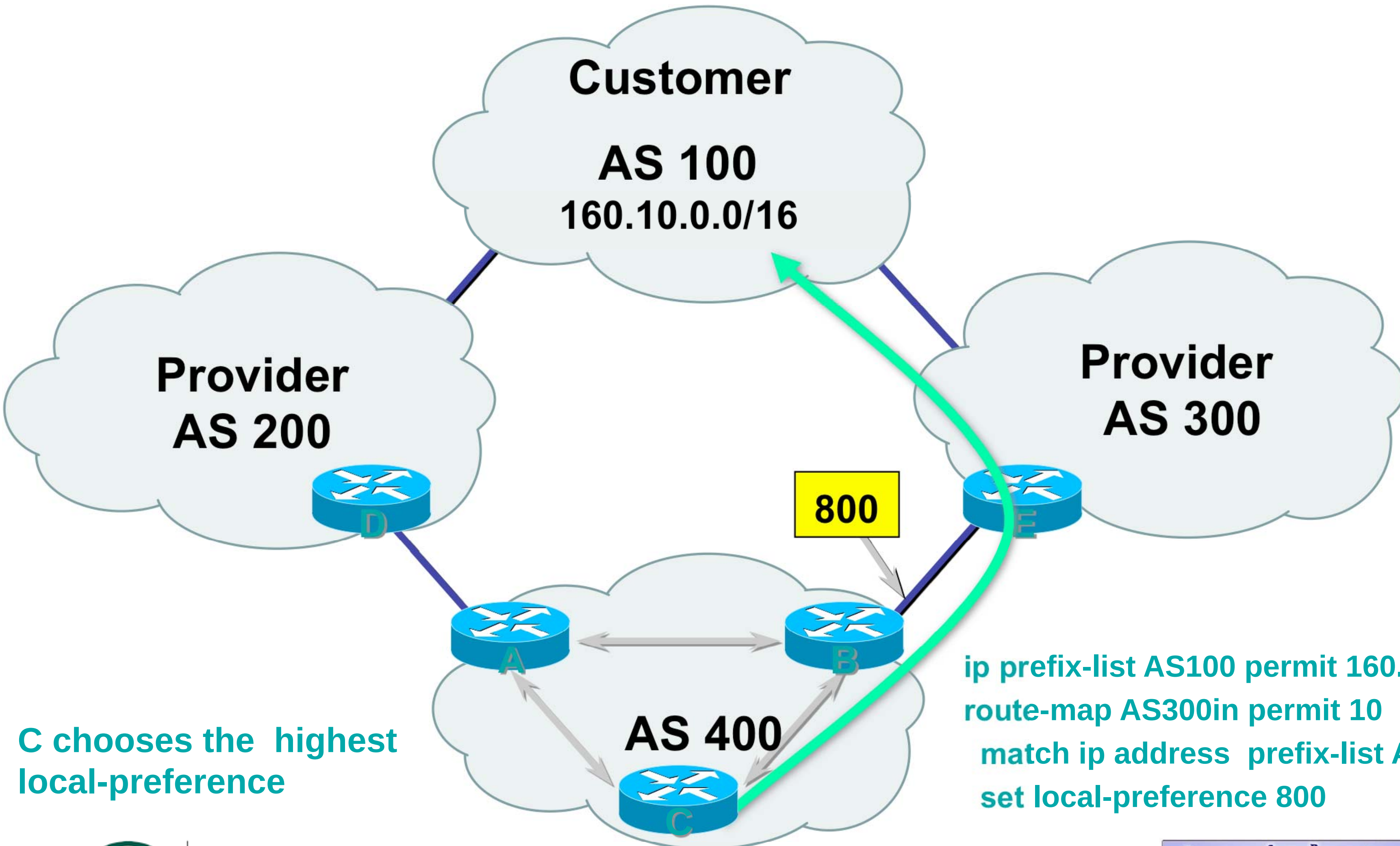
- Medium memory/CPU requirements
- “Best” path – usually the shortest AS-PATH
- Use local-preference to override based on prefix, as-path, or community
- IGP metric to default used for all other destinations

Customer+Default from All Providers



C chooses the shortest AS-PATH

Customer Routes from All Providers



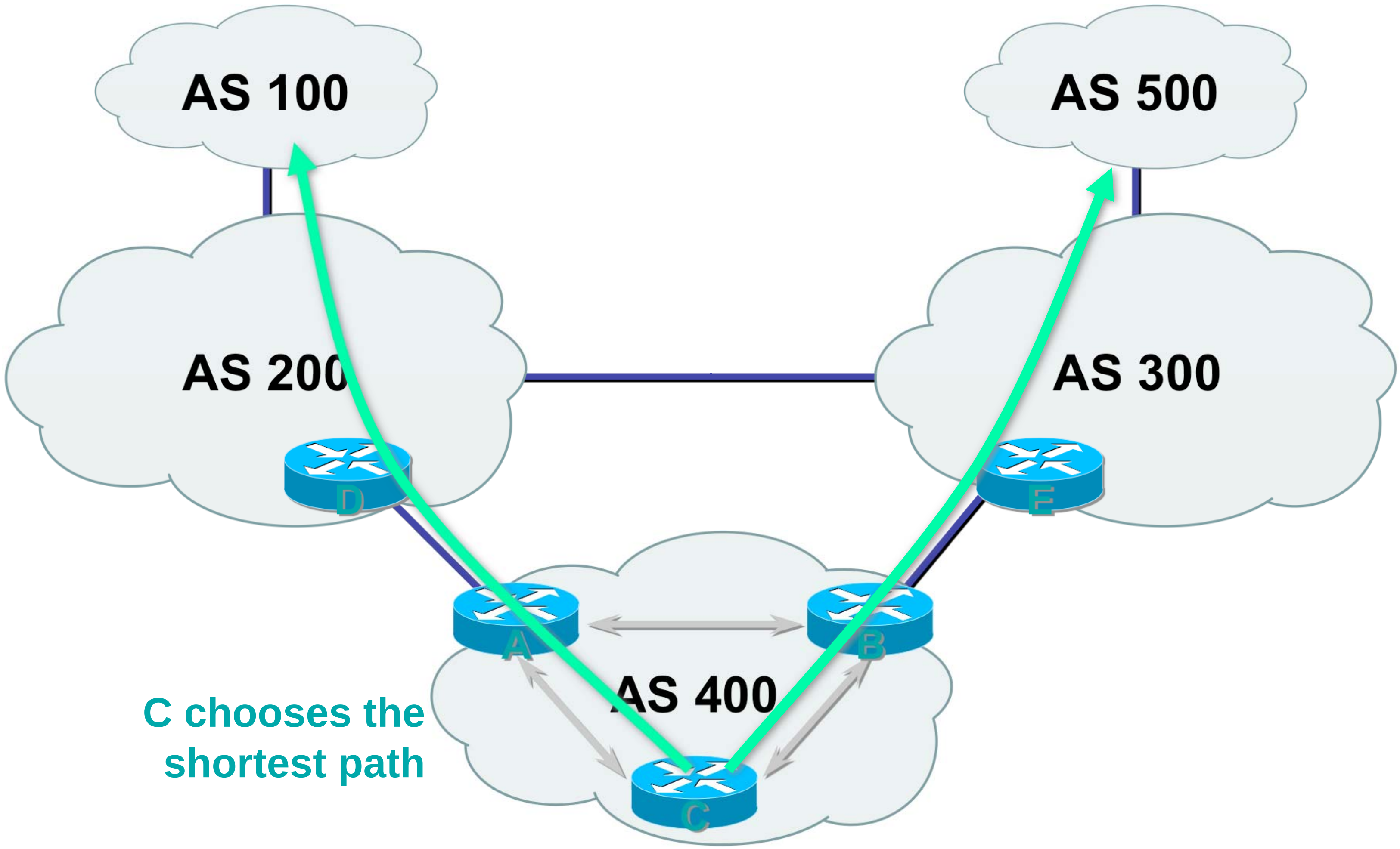
ip prefix-list AS100 permit 160.10.0.0/16
route-map AS300in permit 10
match ip address prefix-list AS100
set local-preference 800

C chooses the highest local-preference

Full Routes from All Providers

- Higher memory/CPU requirements
- Reach all destinations based in the “best” path – usually the one with the shortest path
- Still can adjust manually using local-preference and comparing as-path, communities and prefix-lists

Full Routes from All Providers



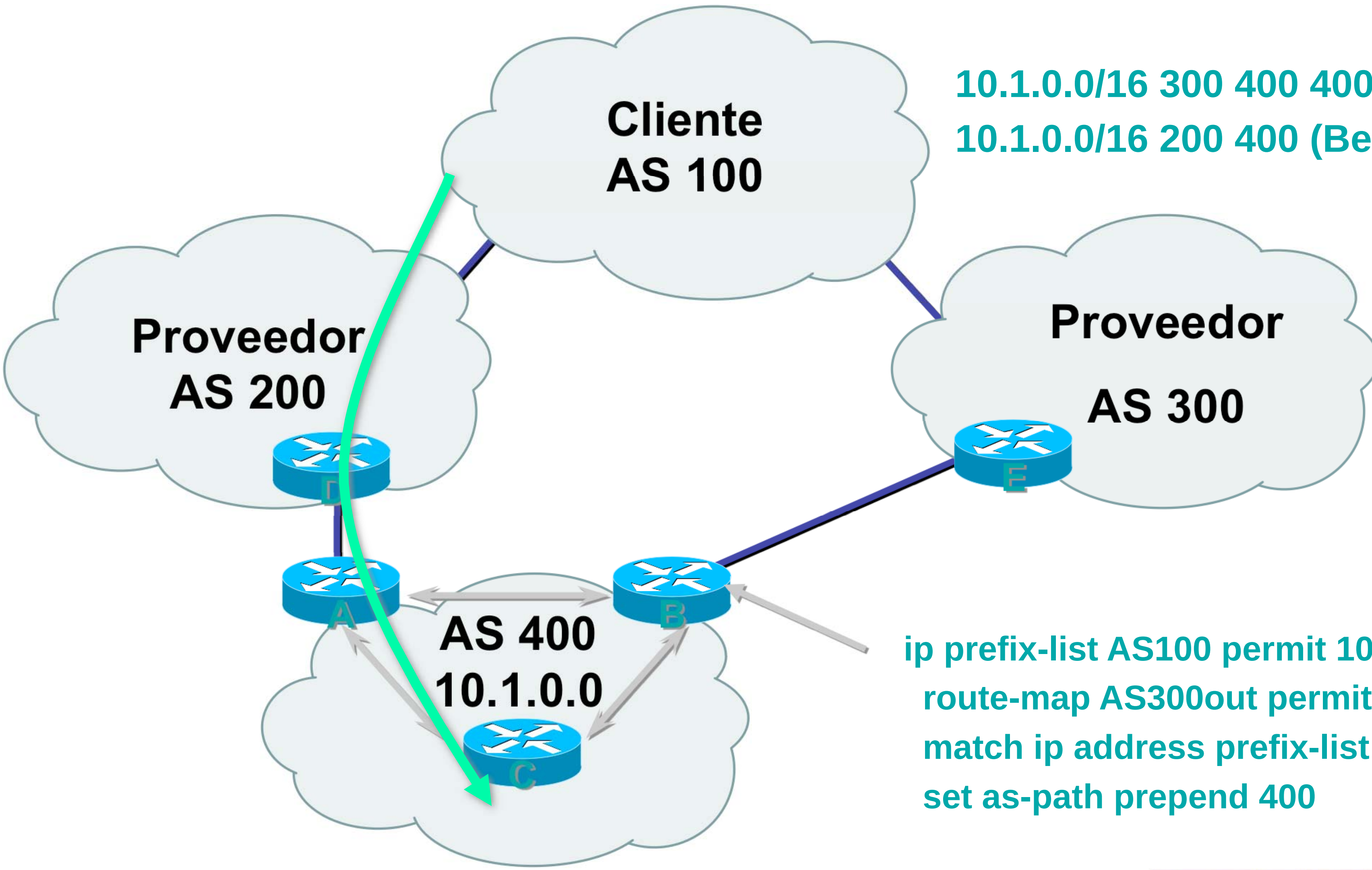
Controlling Inbound Traffic?

- Controlling inbound traffic is very difficult due to lack of a transitive metric
- You can split your prefix announcements among the providers, but then, what happens to redundancy?

Controlling Inbound Traffic?

- Bad Internet Citizen:
  - Splits the address space
  - Uses “as-path prepend”
- Good Internet Citizen:
  - Splits address space
  - Uses “advertise maps”

Using “*AS-PATH prepend*”

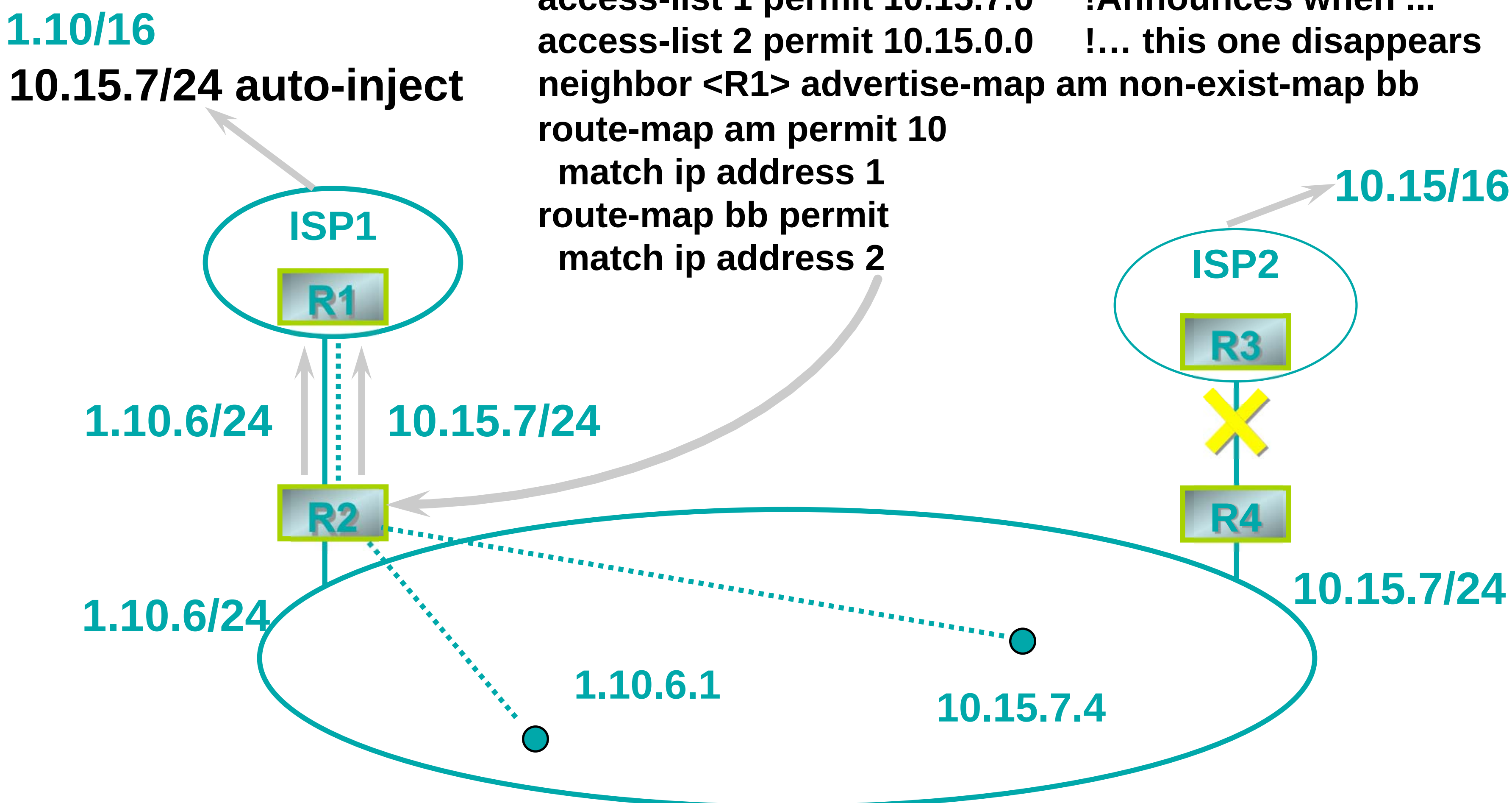


10.1.0.0/16 300 400 400
10.1.0.0/16 200 400 (Best)

ip prefix-list AS100 permit 10.1.0.0/16
route-map AS300out permit 10
match ip address prefix-list AS100
set as-path prepend 400

Using an “*Advertise-Map*”

```
access-list 1 permit 10.15.7.0     !Announces when ...
access-list 2 permit 10.15.0.0     !… this one disappears
neighbor <R1> advertise-map am non-exist-map bb
route-map am permit 10
  match ip address 1
route-map bb permit
  match ip address 2
```



Until Now …

- Stability via:
  - Aggregation
  - Multihoming
  - Inbound/Outbound Filtering
- Scalability of Memory/CPU:
  - Default, customer routes, full routes
- Simplicity using "standard" solutions

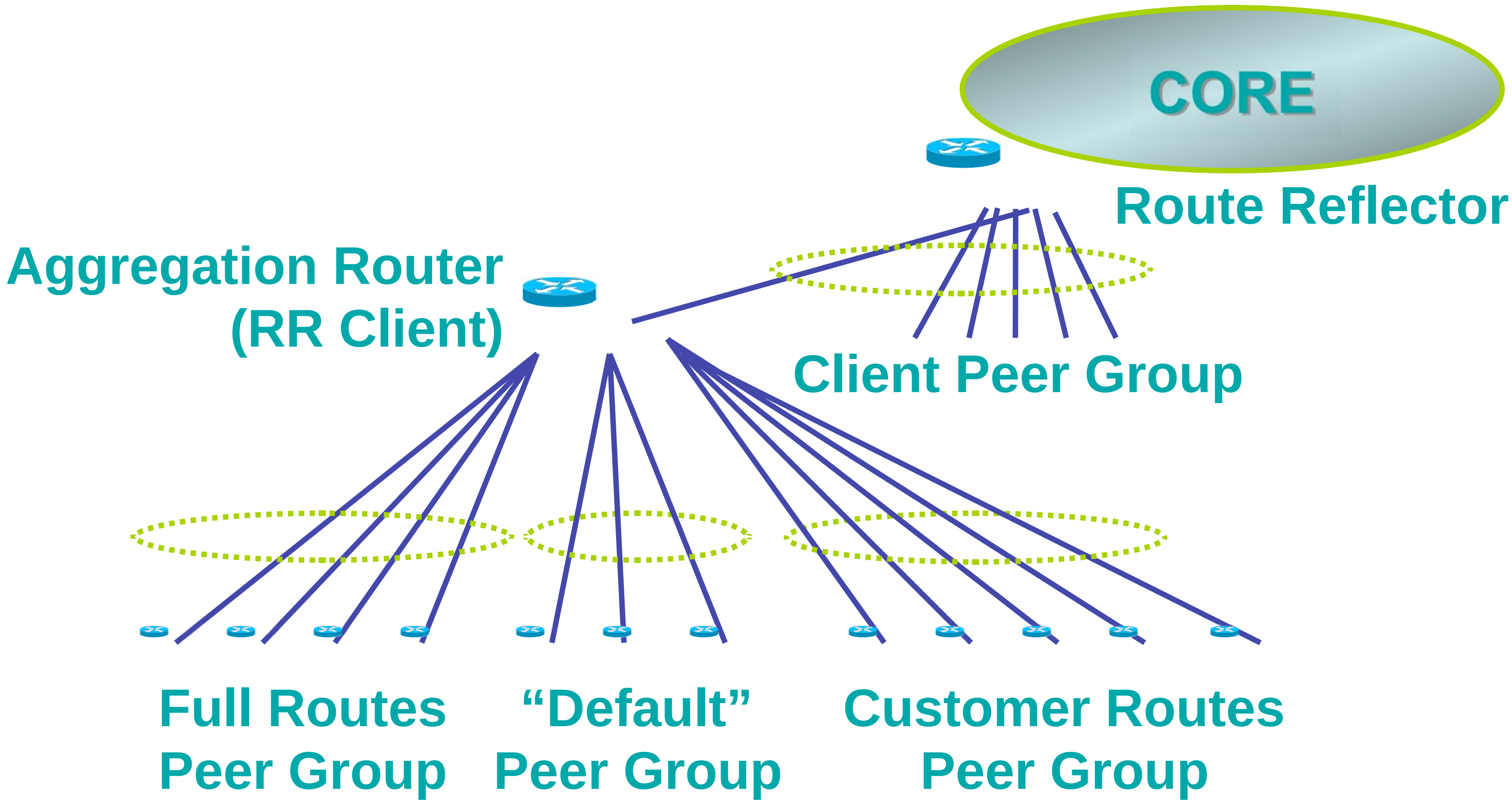
ISP Issues

- Scale customer aggregation using BGP
- Offer a choice of route feeds
- Peer with other providers
- Minimize BGP activity and protect against customer's misconfigurations
- Provide a backup service
- Propagate a QoS policy

Guidelines for Customer Aggregation

- Define at least three *"peer-groups"*:
  - cust-default – send default route only
  - cust-customer – send customer's routes only
  - cust-full – send all routes
- Identify prefixes using communities
  - 2:100=customers; 2:80=peers
- Apply passwords and an inbound prefix-list on a per neighbor basis

Customer Aggregation



NOTE: Apply passwords and inbound prefix list to each customer

cust-full Peer-group

```
neighbor cust-full peer-group
neighbor cust-full description Send all routes
neighbor cust-full remove-private-as
neighbor cust-full version 4
neighbor cust-full route-map cust-in in
neighbor cust-full prefix-list cidr-block out
neighbor cust-full route-map full-routes out
.
ip prefix-list cidr-block seq 5 deny 10.0.0.0/8 ge 9
ip prefix-list cidr-block seq 10 permit 0.0.0.0/0 le 32
```

cust-full outgoing route-map

```
ip community-list 1 permit 2:100
ip community-list 80 permit 2:80
.
route-map full-routes permit 10
  match community 1 80          ; customers & peers
  set metric-type internal      ; MED = IGP metric
  set ip next-hop peer-address ; ours
```

cust-in route-map

```
route-map cust-int permit 10
  set metric 4294967294          ; ignore MED
  set ip next-hop peer-address
  set community 2:100 additive
```

cust-customer peer-group

neighbor cust-customer peer-group
neighbor cust-customer description Customer Routes
neighbor cust-customer remove-private-as
neighbor cust-customer version 4
neighbor cust-customer route-map cust-in in
neighbor cust-customer prefix-list cidr-block out
neighbor cust-customer route-map cust-routes out

cust-routes route-map

```
route-map cust-routes permit 10
  match community 1              ; customers only
  set metric-type internal       ; MED = igp metric
  set ip next-hop peer-address  ; ours
```

default-route peer-group

```
neighbor cust-default peer-group
neighbor cust-default description Send Default
neighbor cust-default default-originate  route-map default-route
neighbor cust-default remove-private-as
neighbor cust-default version 4
neighbor cust-default route-map cust-in in
neighbor cust-default prefix-list deny-all out

ip prefix-list deny-all seq 5 deny 0.0.0.0/0 le 32
```

default-route route-map

```
route-map default-route permit 10
  set metric-type internal          ; MED = igp-metric
  set ip next-hop peer-address  ; ours
```

Peer Groups for IXPs & NAPs

- Similar to eBGP customer aggregation except inbound prefix filtering is rarely used
- Instead use *maximum-prefix* and prefix sanity checking
- Continue to use passwords for each neighbor!

Peer Groups for IXPs & NAPs

neighbor nap peer-group
neighbor nap description from ISP A
neighbor nap remove-private-as
neighbor nap version 4
neighbor nap prefix-list sanity-check in
neighbor nap prefix-list cidr-block out
neighbor nap route-map nap-out out
neighbor nap maximum prefix 30000

Peer Groups for IXPs & NAPs

```
route-map nap-out permit 10
  match community 1                ; customers only
  set metric-type internal         ; MED = IGP metric
  set ip next-hop peer-address  ; ours
```

Peer Groups for IXPs & NAPs : Prefix-List sanity-check

```
# First filter our own address space!!
#deny default
ip prefix-list sanity-check seq 5 deny 0.0.0.0/32
#deny anything beginning with 0
ip prefix-list sanity-check seq 10 deny 0.0.0.0/8 le 32
#deny masks  > 20 for all class A networks (1-127)
ip prefix-list sanity-check seq 15 deny 0.0.0.0/1 ge 20
#deny 10/8 per RFC1918
ip prefix-list sanity-check seq 20 deny 10.0.0.0/8 le 32
# reserved by IANA – loopback address
ip prefix-list sanity-check seq 25 deny 127.0.0.0/8 le 32
#deny masks >= 17 for all class B networks (129-191)
ip prefix-list sanity-check seq 30 deny 128.0.0.0/2 ge 17
#deny network 128.0 – reserved by IANA
ip prefix-list sanity-check seq 35 deny 128.0.0.0/16 le 32
```

Peer Groups for IXPs & NAPs: Prefix-List sanity-check

```
#deny 172.16 perRFC1918
ip prefix-list sanity-check seq 40 deny 172.16.0.0/12 le 32
#deny class C 192.0.20.0 reserved by IANA
ip prefix-list sanity-check seq 45 deny 192.0.2.0/24 le 32
#deny class C 192.0.0.0 reserved by IANA
ip prefix-list sanity-check seq 50 deny 192.0.0.0/24 le 32
#deny 192.168/16 per RFC1918
ip prefix-list sanity-check seq 55 deny 192.168.0.0/16 le 32
#deny 191.255.0.0 – reserved by IANA (Creo ??)
ip prefix-list sanity-check seq 60 deny 191.255.0.0/16 le 32
#deny masks > 25 for class C (192-222)
ip prefix-list sanity-check seq 65 deny 192.0.0.0/3 ge 25
#deny anything in 223 – reserved by IANA
ip prefix-list sanity-check seq 70 deny 223.255.255.0/24 le 32
#deny class D/Experimental
ip prefix-list sanity-check seq 75 deny 224.0.0.0/3 le 32
```

Summary

- Scalability:
  - Use attributes, specially COMMUNITY
  - Use peer-groups and route-reflectors
- Stability:
  - Use loopback addresses for iBGP
  - Generate Aggregates
  - Use passwords per BGP session
  - Always filter inbound and outbound announcements

Summary

- Simplicity – use of standard solutions:
  - Three options for multihoming
  - Group customers using communities
  - Apply standard policies at the edge
  - Avoid "special configurations"
  - Automate configuration generation (RR & RtConfig)

References:

- Cisco (www.cisco.com)
- Dave Meyer (dmm@cisco.com)
- John Stewart, BGP4, Addison Wesley
- Sam Halabi, “Internet Routing Architectures”, Cisco Press
- RFCs

Examples for Customer Filters

ip prefix-list announce-my-prefix seq 10 permit <network>/<prefix_mask> ge 23

ip prefix-list announce-my-prefix seq 100 deny 0.0.0.0/32 le 32

ip prefix-list accept-default seq 10 permit 0.0.0.0/0 ge 32

ip prefix-list accept-default seq 100 deny 0.0.0.0/0 le 31

access-list 10 permit <network> <wildcard_mask>

access-list 10 deny any

access-list 20 permit 0.0.0.0 0.0.0.0

access-list 20 deny any